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United States Patent [19]

Choi

[11] **Patent Number:** **6,141,554**

[45] **Date of Patent:** **Oct. 31, 2000**

[54] **METHOD FOR PROCESSING HARD HANDOFF IN A DIGITAL COMMUNICATION SYSTEM**

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[73] Assignee: **Samsung Electronics Co., Ltd.,** Rep. of Korea

[21] Appl. No.: **09/206,413**

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[30] **Foreign Application Priority Data**

Dec. 9, 1997 [KR] Rep. of Korea 97-66985

[51] **Int. Cl.^{7}** **H04Q 7/20**

[52] **U.S. Cl.** **455/436; 455/442; 455/443; 455/439**

[58] **Field of Search** 455/436, 437, 455/438, 439, 440, 441, 442, 443, 444; 370/332, 331

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Primary Examiner—Nguyen Vo
Assistant Examiner—Duc Nguyen
Attorney, Agent, or Firm—Dillworth & Barrese

[57] **ABSTRACT**

Method for processing hard handoff to prevent unnecessary frequent hard handoffs using specific parameters after the first handoff is performed. The method includes the steps of establishing a Guard_Time period during which handoff is not performed when a mobile station moves slowly in an area in which the cell coverages of the serving and target base stations are overlapped; and establishing a Guard_ Level value so that handoff is performed independent of the Guard_Time if the strength of the radio wave for the moving mobile station is less than the Guard_Level during said Guard_Time. The Guard Time period prevents hard handoff even when a base station controller receives a request for handoff based on information received from the moving mobile station. Although the base station controller prevents the hard handoff dependent on the Guard_Time, the base station controller permits soft handoff and softer handoff to occur normally. The Guard_Time and Guard_ Level are set up according to the base station, the base station controller and the characteristics of the coverage area. The Guard_Time is set up by a system-operator and the Guard_Level is used in relation with the value of T_DROP.

11 Claims, 2 Drawing Sheets
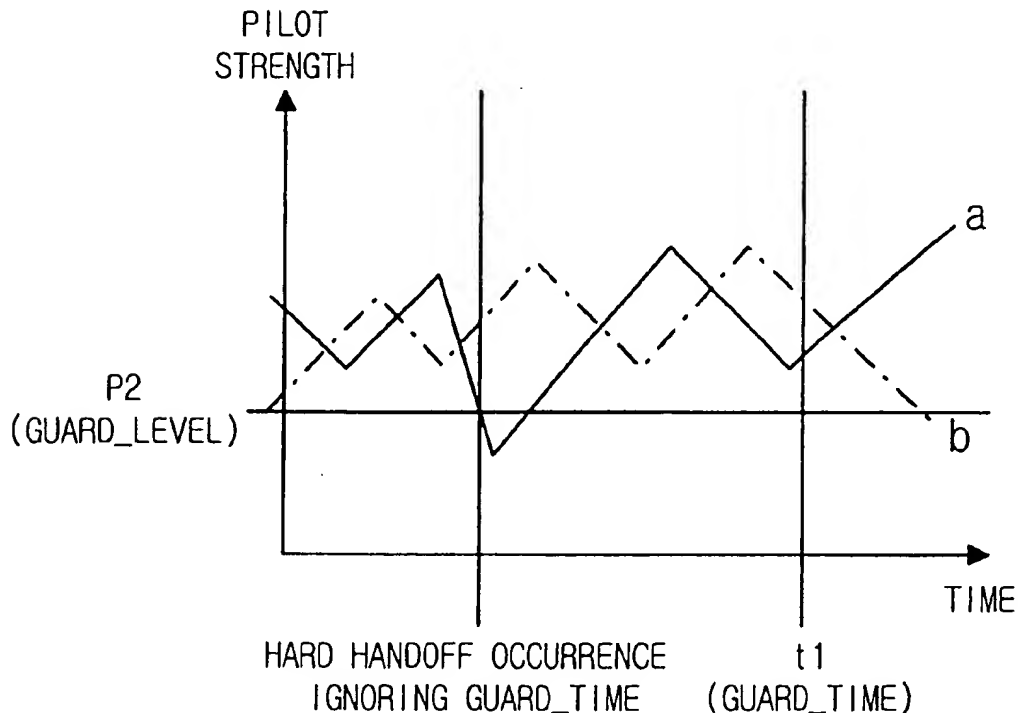
PILOT STRENGTH

P2 (GUARD_LEVEL)

a

b

TIME

t1

HARD HANDOFF OCCURRENCE IGNORING GUARD_TIME (GUARD_TIME)

FIG. 1 (CONVENTIONAL)
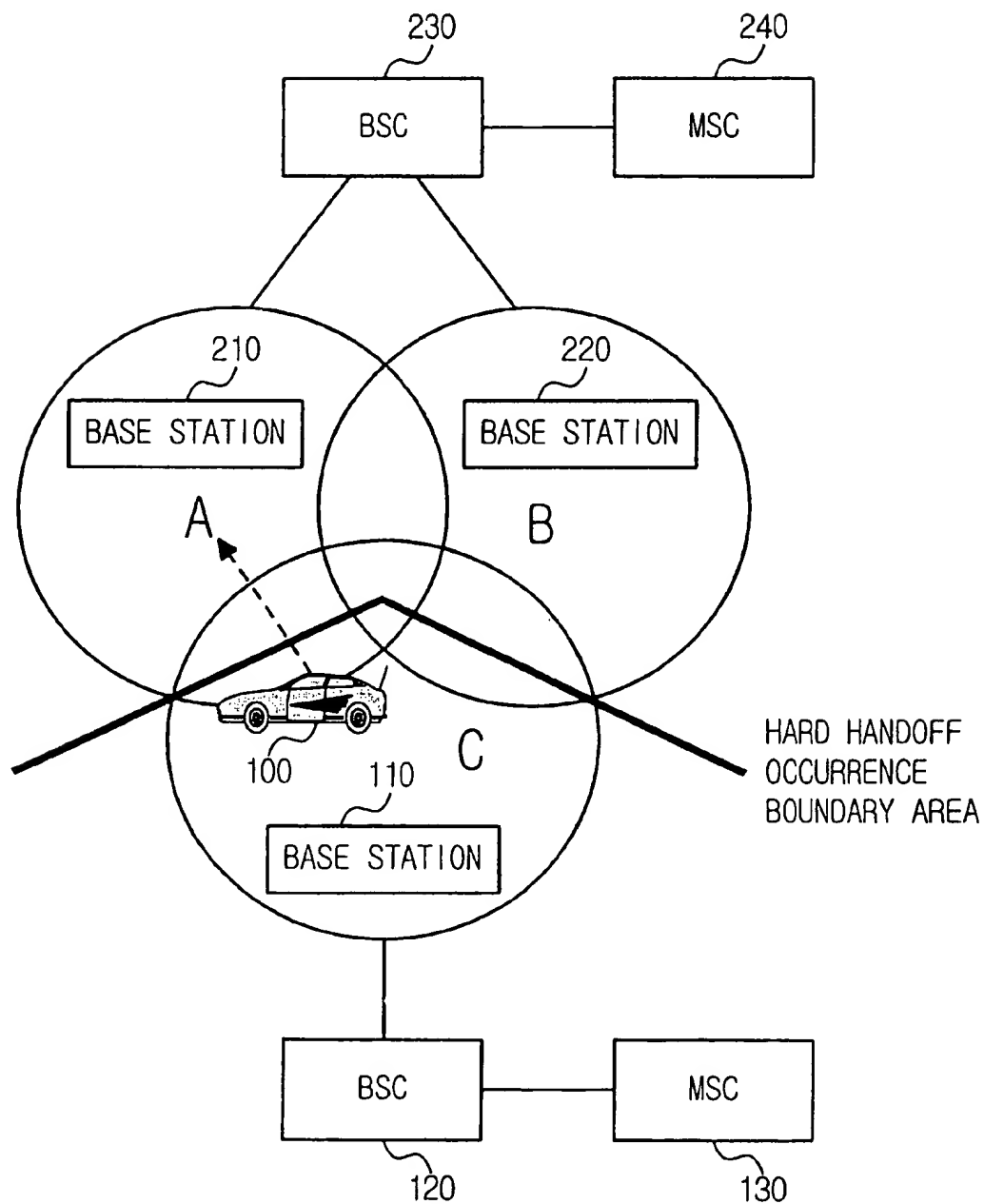

HARD HANDOFF
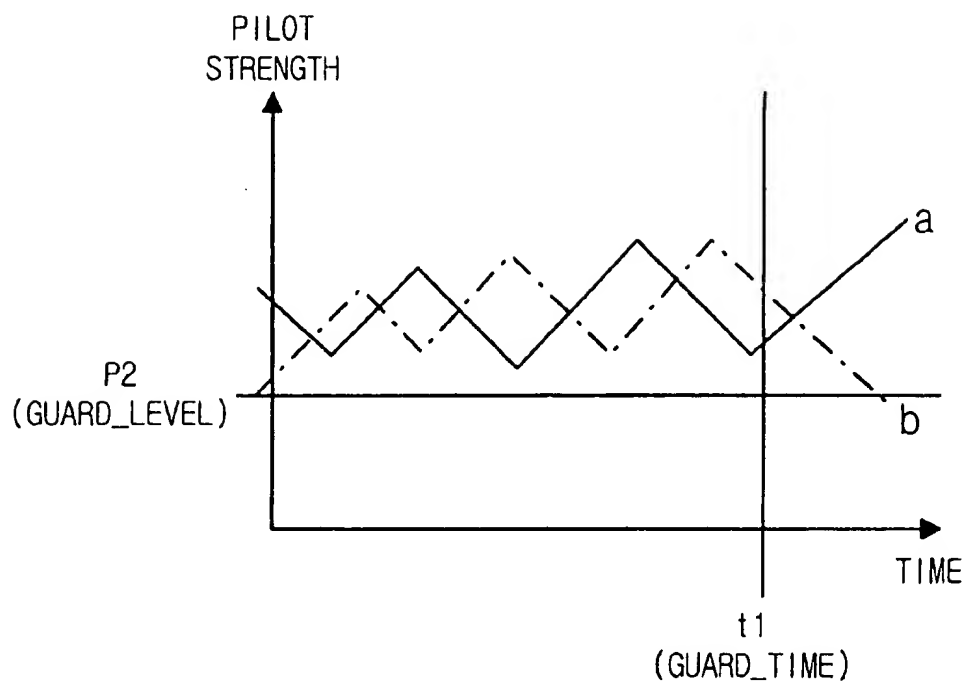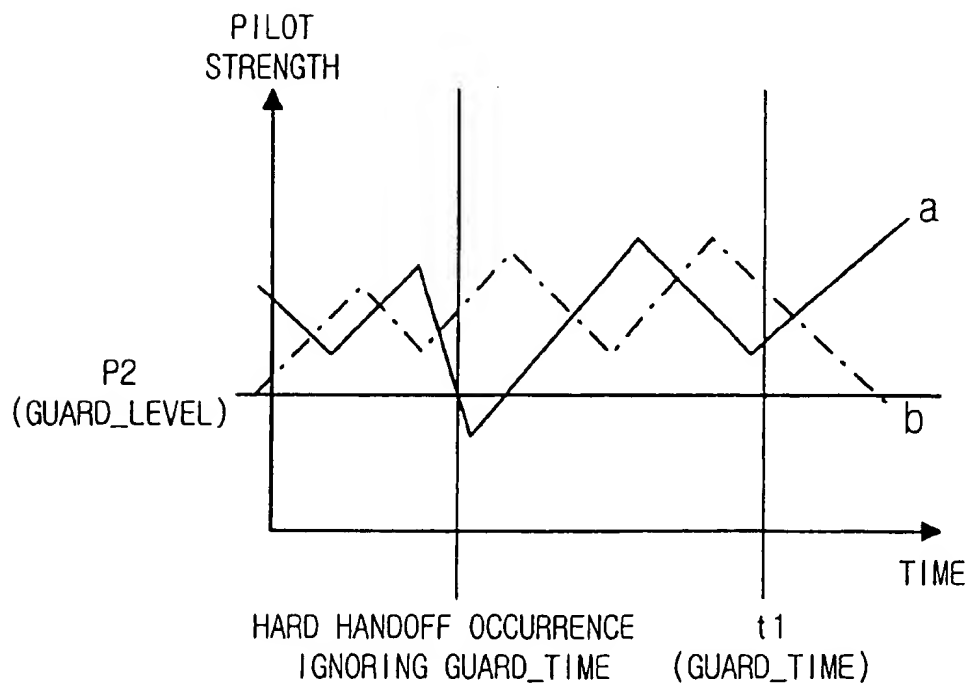OCCURRENCE
BOUNDARY AREA

FIG. 2

FIG. 3

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METHOD FOR PROCESSING HARD HANDOFF IN A DIGITAL COMMUNICATION SYSTEM

FIELD OF THE INVENTION

The present invention relates to digital mobile communication systems. More particularly, it relates to a method for processing hard handoff between a mobile station and base station in a digital mobile communication system.

DESCRIPTION OF THE RELATED ART

Generally, handoff in a digital communication system is performed when a mobile station travels from one serving base station to another target base station. Handoff is the process by which the base station and the mobile station maintain communications when the mobile station travels from one serving base station to another target base station. The types of handoff are soft handoff and hard handoff.

Soft handoff is a handoff that is performed without changing the frequency assignment and frame offset. Additionally, soft handoff is a handoff in which a mobile station moves into a different cell within a base station controller and a softer handoff is a handoff in which the mobile station moves into a different sector within the same cell. Hard handoff is a handoff that includes changing the frequency assignment, frame offset, pseudorandom-noise (PN) offset and the serving mobile switching center.

FIG. 1 shows a conceptual view illustrating a hard handoff between different mobile switching centers (MSC) 130 and 240. As mobile station 100 travels from area C, which is the cell coverage area being served by base station 110, to area A, which is the cell coverage area of the target base station 210, if mobile station 100 receives a radio wave having a strength that is more than a predefined value, T_ADD from the serving base station, the mobile station continues to send its information to the base station 110.

If the strength of the radio wave of the PN offset, which is included in the pilot strength measurement message (PSMM) received by the mobile station 100, is greater than a predefined threshold, T_COMP, base station controller 120 searches the information to perform the hard handoff. As a result of the search, if the PN offset does not correspond to the serving base station 110 of a mobile switching center 130 but to target base station 210 of another mobile switching center 240, base station controller 120 sends a request to mobile switching center 130 in which the base station controller 120 is included. The mobile switching center 130 then sends the request to the mobile switching center 240. The mobile switching center 240, having received the request, sends the request to base station controller 230. Base station controller 230 reserves base station 210 to prepare for handoff of mobile station 100 and responds to mobile switching center 240. Mobile switching center 240, having received the response, passes the response over to mobile switching center 130 that has requested the handoff.

After receiving the response, mobile switching center 130 then responds to the base station controller 120 again. Base station controller 120, which had requested the handoff, determines that base station 210, included in the another mobile switching center 240, has been prepared for the handoff and sends a handoff direction message (HDM) to the mobile station. Mobile station 100 receives the message, synchronizes to the base station 210, and then sends a handoff completion message (HCM) to the base station controller 230. The base station controller 230 having received the message, advises the mobile switching center

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240 that the handoff of the mobile station 100 has been normally performed. Once the mobile switching center 240 advises the mobile switching center 130 of the above result, the mobile switching center 130 advises base 120, which then releases all resources having been assigned to mobile station 100. Base station 110 also releases its resources assigned to mobile station 100. After the above steps are performed, the serving base station for mobile station 100 is changed from base station 110 to base station 210. Additionally, the radio wave, which serves the mobile station, is changed from the radio wave of base station 110 to the radio wave of base station 210. After the hard handoff is successfully achieved, if the mobile station again receives a radio wave of a base station included in an another mobile switching center, and the radio wave has a value more than a specific value, the hard handoff is immediately performed again.

As stated above, conventionally, the hard handoff is immediately performed as would a soft handoff, without any particular consideration. The parameter which the base station controller uses to determine the hard handoff is the strength of PN offset in the pilot strength measurement message (PSMM) message received in accordance with the predetermined values, T_ADD and T_COMP by the mobile station. Therefore, if the base station controller unconditionally performs the hard handoff, the success rate of hard handoff is less than the success rate of soft handoff, and the quality of voice received decreases in the mobile station as a result of the frequent hard handoff.

In addition, the unconditionally performed hard handoff causes an overload to the base station controller and the base station as well as the target mobile switching center. Consequently, this affects the performance of the overall system. The problems in the conventional method as stated above are summarized as follows:

First, the value of strength of the present pilot in the pilot strength measurement message (PSMM) is the only parameter used in determining whether or not to perform hard handoff of the mobile station. Therefore, it is difficult for a mobile station to maintain a stable call under the rapidly changing circumstances.

Second, the base station controller determines the hard handoff using only the predetermined values of T_ADD and T_COMP, so if a mobile station is in an overlapping area in between the cell of serving base station and the cell of target base station being included in another mobile switching center, the measurements associated with the radio wave more easily reach the predefined values of the mobile station and cause unnecessary hard handoff on a constant basis.

Third, the hard handoff between mobile switching centers, in its characteristics, has the lower success rate than the soft handoff, so when the hard handoffs are performed frequently, it is difficult to maintain a stable call of a mobile station.

Fourth, when a mobile station performs hard handoffs constantly, the mobile switching center, base station controller and the base station should allocate resources for the corresponding services. Consequently, the conventional method is not profitable with respect to resource-effectiveness.

Fifth, when a mobile station performs hard handoffs constantly, the mobile switching center, base station controller and the base station have definite overloads, which affects the overall performance.

SUMMARY OF THE INVENTION

The present invention is intended to provide method for processing hard handoffs being performed between a mobile

station and base station in a digital mobile communication system. The method for processing hard handoff prevents unnecessary frequent hard handoffs using specific parameters after the first handoff is performed.

For solving the conventional problems, when a mobile station travels from a cell coverage area being served by a base station belonging to a mobile switching center, to the cell coverage area of a target base station belonging to another mobile switching center, a preferable embodiment of the method for processing hard handoff according to the present invention comprises the steps of:

establishing a Guard_Time during which handoff is not performed while a mobile station moves slowly in an area in which the cell coverage of the serving and target base stations are overlapped, even though a base station controller receives a request for handoff based on the information received from the moving mobile station; and

establishing a Guard_Level as a specific value so that handoff is performed independently of the Guard_Time if the strength of the radio wave for the moving mobile station is less than the Guard_Level during said Guard_Time.

According to the method of present invention, even though the base station controller prevents the hard handoff in dependence on the Guard_Time, the base station controller permits soft handoff to occur normally.

In one embodiment, it is preferable that the Guard_Time and Guard_Level are set up according to the base station, the base station controller and the characteristics of the area. The Guard_Time may be set up by a system-operator, and the range of the Guard_Time can be set up between 0 to 60 seconds in accordance with another embodiment.

According to another embodiment of the present invention, it is preferable that the Guard_Level is used as an interrelation with the value of T_DROP and the Guard_Level has a value from –20 dB to –5 dB.

Other objects and advantages of the invention will become apparent upon reading the detailed description and upon reference to the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a structural view illustrating a cell-structure in which hard handoff between mobile switching centers can occur;

FIG. 2 is a graphical representation illustrating the method for processing and controlling hard handoff using a Guard_Level and a Guard_Time value according to an embodiment of the invention; and

FIG. 3 is a graphical representation illustrating the method for performing hard handoff when the present pilot drops below the Guard_Level according to an embodiment of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

A preferable embodiment of the method for processing hard handoff between a mobile station and base station in a digital mobile communication system is as follows.

When a mobile station travels from a cell coverage area being served by a base station belonging to a mobile switching center, to a cell coverage area of a target base station belonging to another mobile switching center a Guard_Time is established as specific time period in which handoff is not performed when a mobile station moves

slowly in an area in which the cell coverage area of the serving and target base station are overlapped. Hard handoff is not performed during the Guard_Time even though a base station controller receives a request for in handoff based on the information received from the moving mobile station. A Guard_Level is established as specific value which is used to enable handoff to be performed independently of the Guard_Time if the strength of the radio wave for the moving mobile station is less than the Guard_Level during the Guard_Time.

Although the base station controller prevents the hard handoff dependent on the established Guard_Time, the base station controller permits soft handoff and softer handoff to occur normally. In another embodiment, the Guard_Time and Guard_Level are set up according to the base station, the base station controller and the characteristics of the coverage areas. In another embodiment, the Guard_Time is set up by a system-operator, and it is preferably in the range of between 0 to 60 seconds.

The established Guard_Level is used in relation with the value of T_DROP, and is preferably a value from –20 dB to –5 dB.

FIG. 1 shows a structural view illustrating a cell-structure in which hard handoff between mobile switching centers can occur. As illustrated in FIG. 1, when mobile station 100 travels from a cell area C, of a serving base station 110, to a cell area A of a target base station 210, the mobile station 100 sends information relating to the strength of radio wave that the mobile station 100 is currently receiving from the serving base station 110. The base station controller 120 receives this signal strength information and determines whether a handoff is to be performed and which handoff is to be performed.

As illustrated in FIG. 1, if a hard handoff between mobile switching centers occurs, the mobile station 100 receives service through base station controller 230 and base station 210 which are included in the mobile switching center 240 when passing over the cell area A. Once the hard handoff is successfully performed, the mobile station receives the pilot waves from the base station 210 serving the cell area A and base station 110 serving the cell area C, simultaneously. In the above case, the mobile station may receive powerful radio waves from the target base station rather than the serving base station.

FIG. 2 shows a view illustrating the control of hard handoff using the Guard_Level and Guard_Time in accordance with an embodiment of the invention. As illustrated, it is possible for the strength of pilot wave "a" of the serving base station, and pilot wave "b" of the target base station to change suddenly. The base station controller prevents the mobile station from frequently leading to the hard handoff made in a short time by implementing a predefined Guard_Time t1, to maintain the stability of call. That is, the Guard_Time is a predefined specific time period in which hard handoff is not performed, even though the base station controller receives a request for handoff based on the information received by the mobile station.

FIG. 3 shows a graphical representation of the method for performing hard handoff when the present pilot drops below the Guard_Level P2. As illustrated, in the real operating circumstances, the pilot of the serving base station for the mobile station suddenly becomes poor during the Guard_Time period. Thus, if the pilot "a" of the base station drops below the predefined Guard_Level P2, hard handoff occurs regardless of the non-expiration of the Guard_Time period.

The base station controller restricts the hard handoff dependent on the established Guard_Time, however, the

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soft handoff and softer handoff occur normally so that the mobile station can maintain the stability of call and all of the other functions can work normally. The Guard_Time and Guard_Level are established according to the base station, the base station controller and the characteristics of the area.

The mobile station to which the Guard_Time is applied does not unconditionally perform a hard handoff when the pilot of the serving base station becomes momentarily poor, and the mobile station receives a more powerful pilot of the target base station so that the stability of call is maintained. As illustrated in FIG. 1, if the mobile station 100 travels from cell area A to the overlapping cell area B, soft handoff occurs. Consequently, it induces the mobile station to perform soft handoff rather than hard handoff, wherein the soft handoff is better in the success rate and the quality of voice received, so the mobile station can travel maintaining the stability of call. Additionally, the hard handoff does not constantly occur in a short time, so it is possible to reduce the termination of the call resulting from under performing of hard handoff.

The present invention as stated above has effects as follows.

First, as the invention does not simply consider the pilot strength information when performing hard handoff for a mobile station, it can induce soft handoff to be performed, which has the higher success rate and maintains the stability of call.

Second, by using an established Guard_Time, it is possible to maintain the stability of call by preventing the hard handoff from frequently occurring in a short time under the rapidly changing circumstances associated with the traveling mobile station.

Third, it is possible to induce the soft handoff rather than hard handoff wherein the hard handoff may cause a cut or break in the voice communication to maintain the quality of telephone conversation clearly.

Fourth, it is possible to satisfy the diverse conditions by performing hard handoff using the established Guard_Level if the level of the presently received pilot wave drops below the specific value, while the frequent occurrence of hard handoff within the handoff range is prevented.

Fifth, it is possible to save system resources by preventing unnecessary hard handoffs when a mobile station would otherwise frequently perform hard handoffs between mobile switching centers.

Sixth, it is possible to prevent overload to the system wherein the overload occurs by frequently performing the hard handoffs between mobile switching centers.

While the invention is susceptible to various modification and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and will be herein be described in detail. It should be understood, however, that it is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modification, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

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What is claimed is:

1. A method for processing hard handoffs in a digital mobile communication system when a mobile station travels from a cell coverage area being served by a base station belonging to a mobile switching center to a cell coverage area of a target base station belonging to another mobile switching center, said method comprising the steps of:

establishing a Guard_Time period in which hard handoff is not performed when a mobile station moves into an area in which the cell coverage of said serving and target base stations are overlapped; and

establishing a Guard_Level value at which hard handoff is performed independently of said established Guard_Time when the strength of a radio wave for said moving mobile station is less than said established Guard_Level during said Guard_Time.

2. The method as set forth in claim 1, further comprising the step of enabling said base station controller to perform soft handoff and softer handoff normally.

3. The method as set forth in claim 1, wherein said steps of establishing said Guard_Time and said Guard_Level are performed according to the base station, the base station controller and characteristics of the coverage area.

4. The method as set forth in claim 1, said step of establishing said Guard_Time is performed by a system-operator.

5. The method as set forth in claim 4, wherein said Guard_Time is set between 0 to 60 seconds.

6. The method as set forth in claim 1, wherein said established Guard_Level is used in relation with a value T_DROP.

7. The method as set forth in claim 6, wherein said Guard_Level has a value from −20 dB to −5 dB.

8. An apparatus for processing hard handoffs in a digital mobile communication system when a mobile station travels from a cell coverage area being served by a base station belonging to a mobile switching center to a cell coverage area of a target base station belonging to another mobile switching center, the apparatus comprising:

means for establishing a Guard_Time period in which hard handoff is not performed when a mobile station moves into an area in which the cell coverage of said serving and target base stations are overlapped; and

means for establishing a Guard-Level value at which hard handoff is performed independently of said established Guard_Time when the strength of a radio wave for said moving mobile station is less than said established Guard_Level during said Guard_Time.

9. The apparatus of claim 8, further comprising means for enabling said base station controller for perform soft handoff and softer handoff.

10. The apparatus of claim 8, wherein said Guard_Time is set between 0–60 seconds.

11. The apparatus of claim 8, wherein said Guard_Level has a value from −20 dB to −5 dB.

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United States Patent [19]

Black

[11] **Patent Number:** **6,134,440**

[45] **Date of Patent:** *Oct. 17, 2000

[54] **METHOD AND APPARATUS FOR PERFORMING MOBILE STATION ASSISTED HARD HANDOFF USING OFF LINE SEARCHING**

[75] Inventor: **Peter J. Black,** La Jolla, Calif.

[73] Assignee: **Qualcomm Inc.,** San Diego, Calif.

[*] Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

[21] Appl. No.: **09/013,413**

[22] Filed: **Jan. 26, 1998**

[51] **Int. Cl.**[7] **H04Q 7/38**

[52] **U.S. Cl.** **455/436;** 455/437
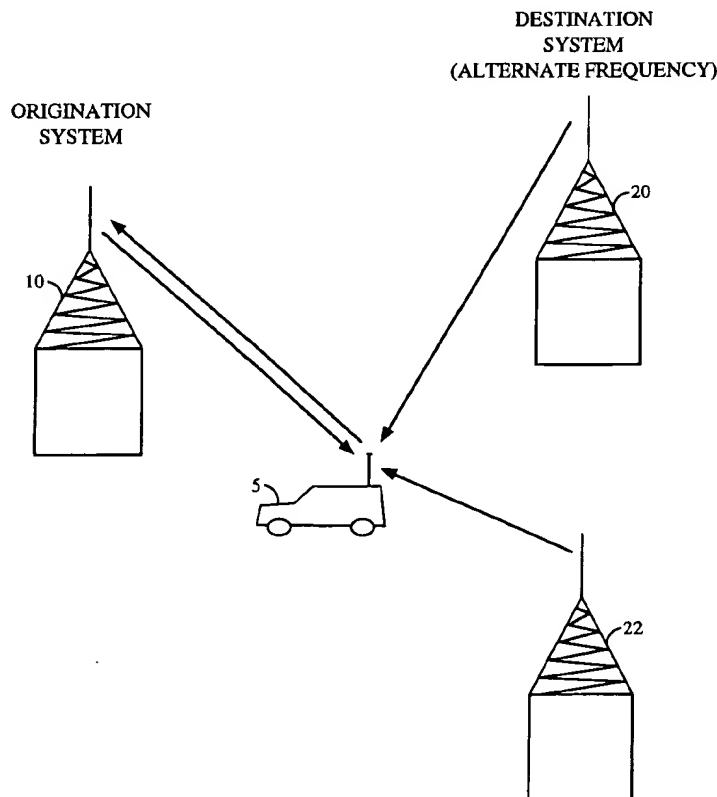
[58] **Field of Search** 455/437, 436, 455/438, 439, 443, 524, 525, 226.1, 226.2, 226.3; 370/331, 332, 333

[56] **References Cited**

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[57] **ABSTRACT**

A method and apparatus for minimizing the amount of time that a mobile station is to be out of communication with an "origination" base station while searching for a suitable system to which to perform a mobile station assisted hard handoff. After being directed to search for pilot signals in an alternate frequency band, the mobile station tunes to that alternate frequency and samples the incoming data, storing those samples in memory. When a sufficient number of samples have been stored, the mobile station retunes to the origination frequency. The forward link data is again received by the mobile station, and reverse link data can be successfully transmitted to the origination base station. After retuning to the origination frequency, a searcher in the mobile station will subsequently be employed to search for pilot signal offsets utilizing the stored data collected from the alternate frequency.

8 Claims, 6 Drawing Sheets

DESTINATION
SYSTEM
(ALTERNATE FREQUENCY)

ORIGINATION
SYSTEM

DESTINATION
SYSTEM
(ALTERNATE FREQUENCY)

ORIGINATION
SYSTEM

10

20

5

22
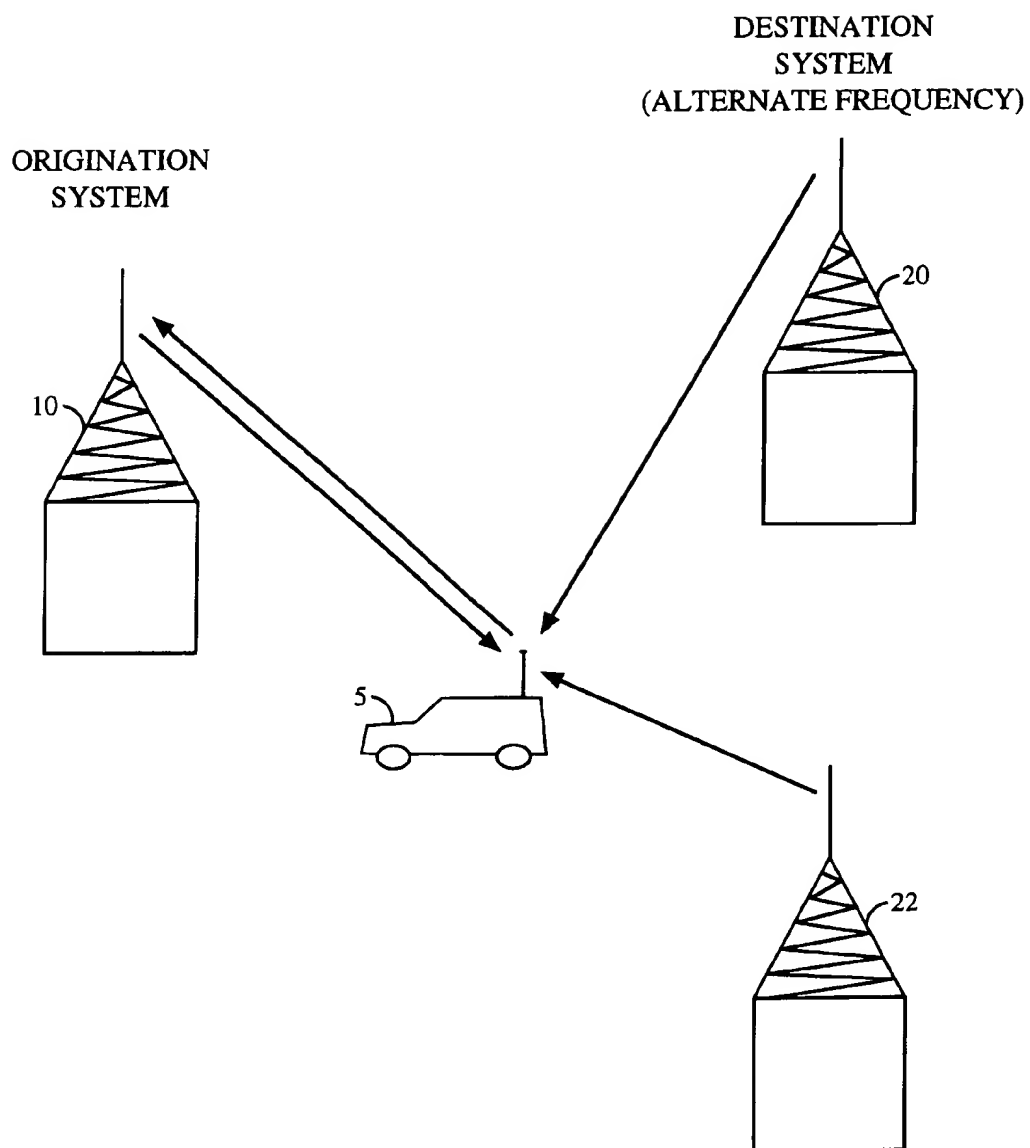
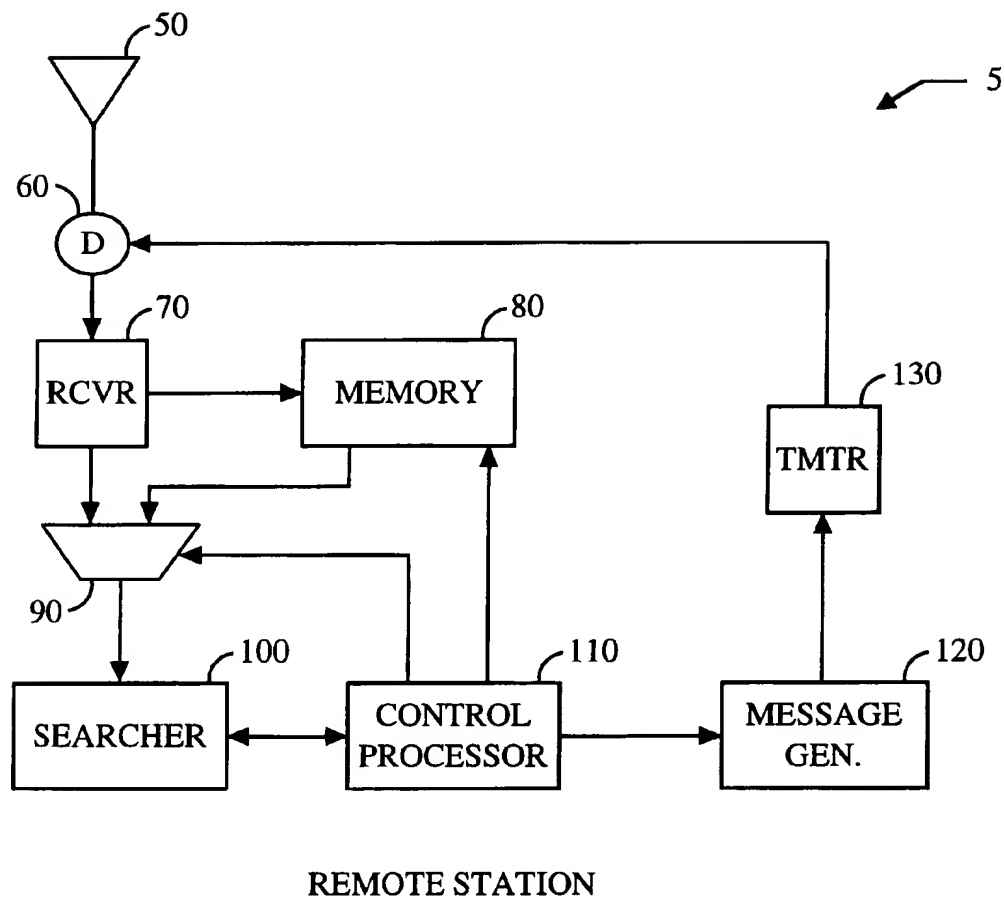FIG. 1
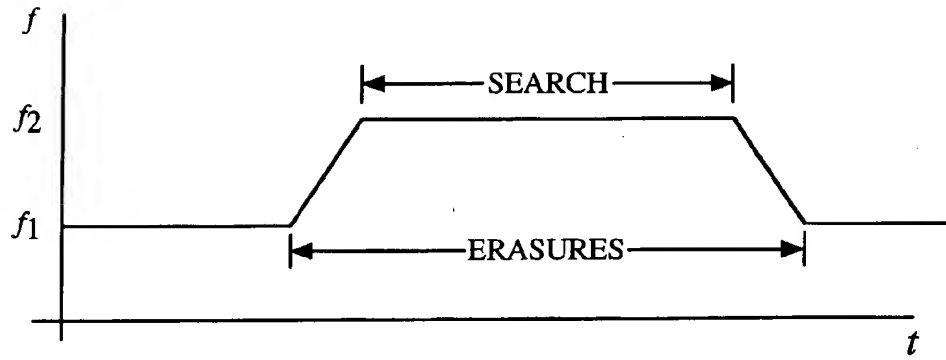
PRIOR ART

FIG. 2A
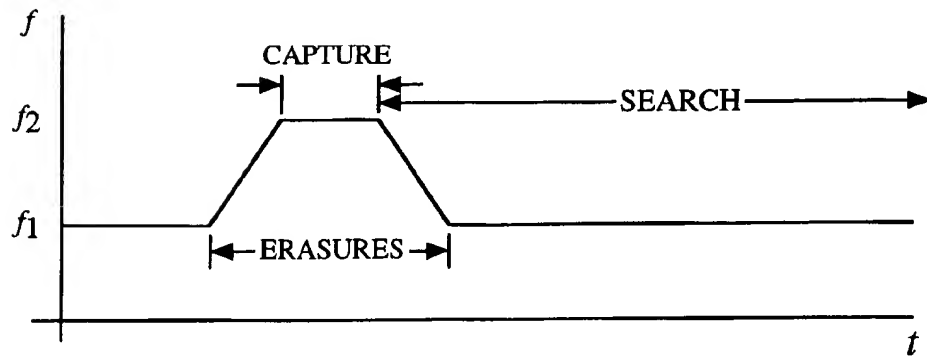
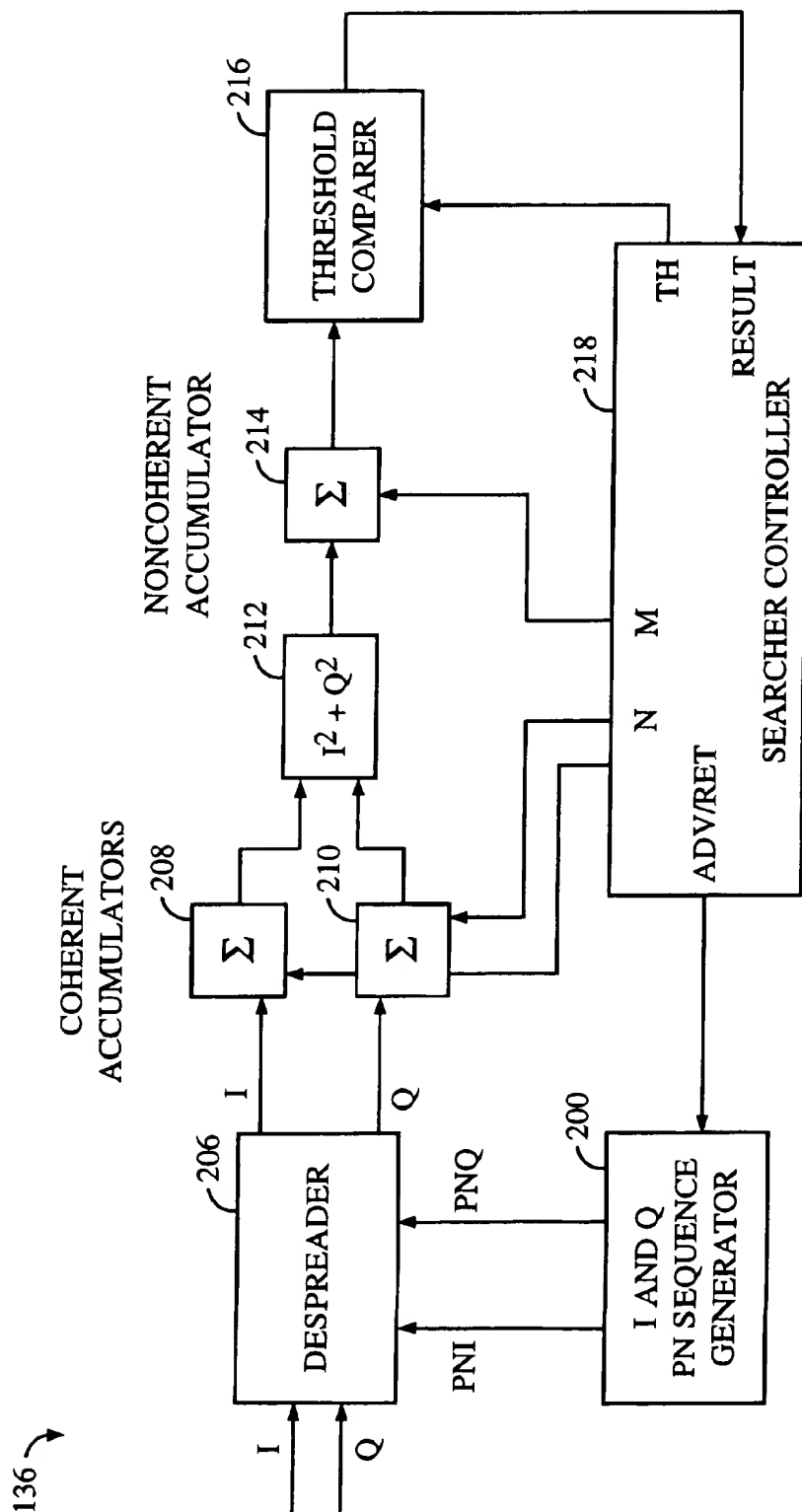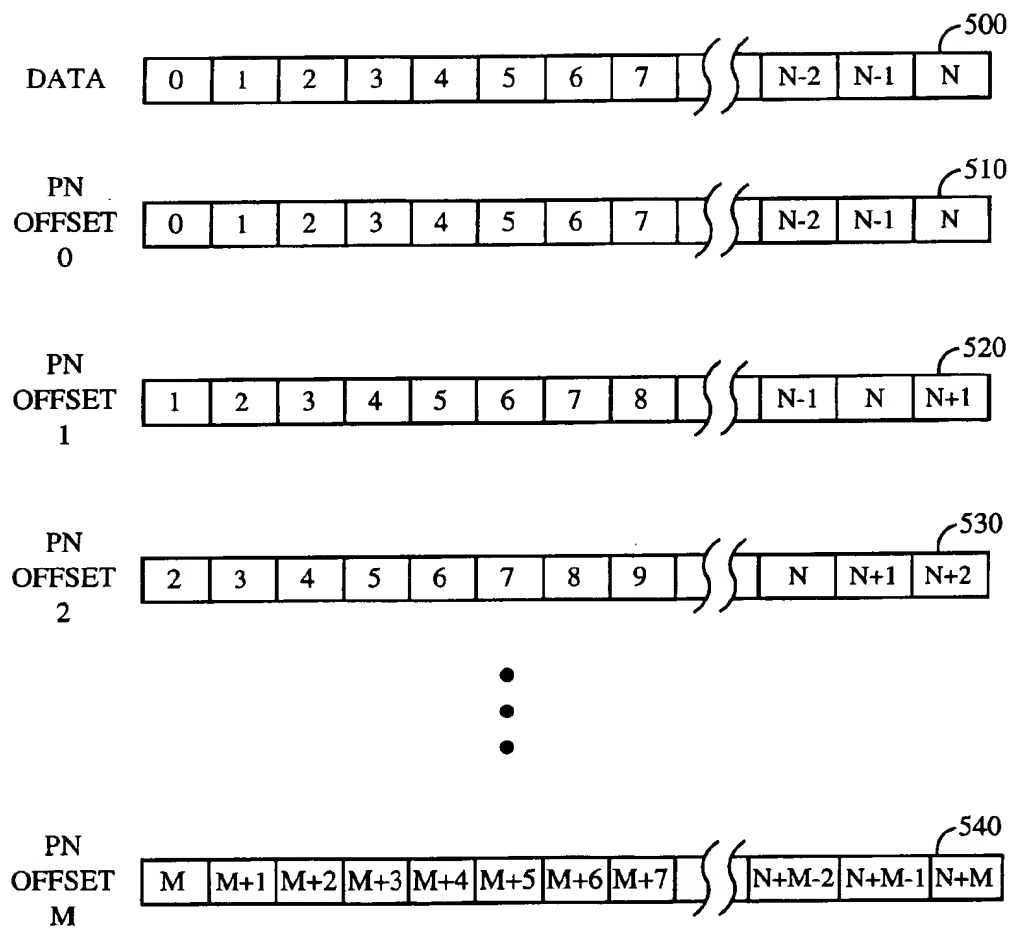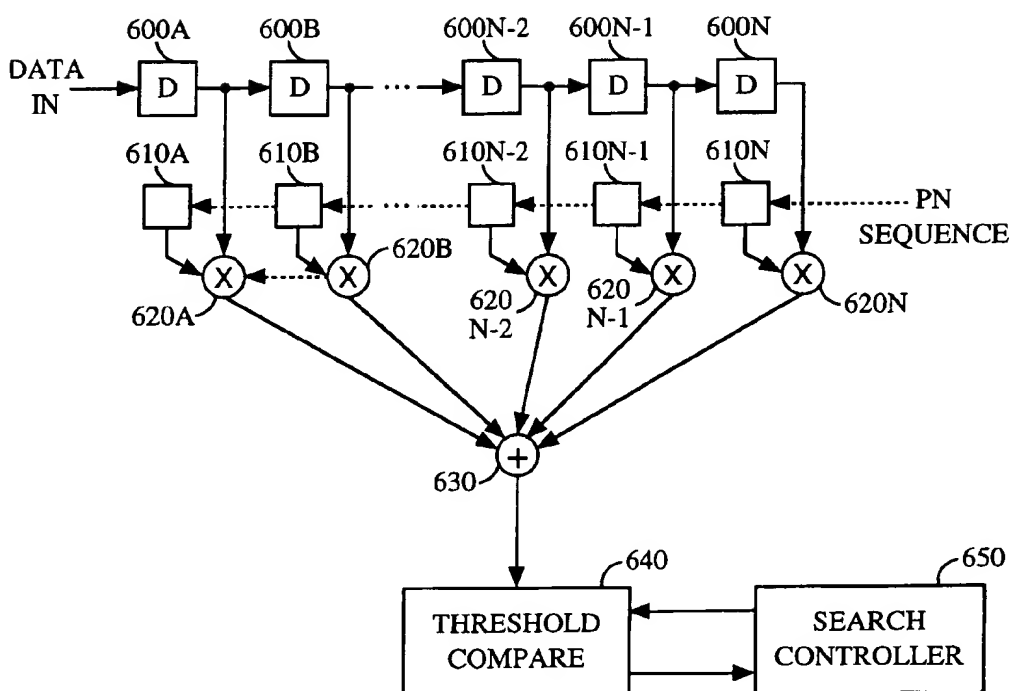FIG. 2B

REMOTE STATION

FIG. 3

FIG. 4

FIG. 5

FIG. 6

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METHOD AND APPARATUS FOR PERFORMING MOBILE STATION ASSISTED HARD HANDOFF USING OFF LINE SEARCHING

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates to communications systems. More particularly, the present invention relates to a novel and improved method for hard handoff between different wireless communication systems.

II. Description of the Related Art

In a code division multiple access (CDMA) spread spectrum communication system, a common frequency band is used for communication with all base stations within that system. An example of such a system is described in the TIA/EIA Interim Standard IS-95-A entitled "Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System", incorporated herein by reference. The generation and receipt of CDMA signals is disclosed in U.S. Pat. No. 4,901,307 entitled "SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEMS USING SATELLITE OR TERRESTRIAL REPEATERS" and in U.S. Pat. No. 5,103,459 entitled "SYSTEM AND METHOD FOR GENERATING WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM" both of which are assigned to the assignees of the present invention and incorporated herein by reference.

Signals occupying the common frequency band are discriminated at the receiving station by using a high rate pseudonoise (PN) code. The PN code modulates signals transmitted from the base stations and the mobile stations. Signals from different base stations can be separately received at the receiving station by discrimination of the unique time offset that is introduced in the PN codes assigned to each base station. The high rate PN modulation also allows the receiving station to receive a signal from a single transmission station where the signal has traveled from the the base station to the receiving station over several different distinct propagation paths (commonly referred to as "multipathing"). Demodulation of multipath signals is disclosed in U.S. Pat. No. 5,490,165 entitled "DEMODULATION ELEMENT ASSIGNMENT IN A SYSTEM CAPABLE OF RECEIVING MULTIPLE SIGNALS" and in U.S. Pat. No. 5,109,390 entitled "DIVERSITY RECEIVER IN A CDMA CELLULAR TELEPHONE SYSTEM", both of which are assigned to the assignee of the present invention and incorporated herein by reference.

The use by all base stations within a particular system of a common frequency band allows simultaneous communication between a mobile station and more than one base station, a condition known as soft handoff. On implementation of a soft handoff method and apparatus is disclosed in U.S. Pat. No. 5,101,501 entitled "SOFT HANDOFF IN A CDMA CELLULAR TELEPHONE SYSTEM" and U.S. Pat. No. 5,267,261 entitled "MOBILE STATION ASSISTED SOFT HANDOFF IN A CDMA CELLULAR COMMUNICATIONS SYSTEM", both assigned to the assignee of the present invention and incorporated herein by reference. Similarly, a mobile station can be simultaneously communicating with two sectors of the same base station, known as softer handoff as disclosed in copending U.S. Patent Application entitled "METHOD AND APPARATUS FOR PERFORMING HANDOFF BETWEEN SECTORS OF A COMMON BASE STATION", U.S. Pat. No. 5,625, 876, issued Apr. 29, 1997, assigned to the assignee of the

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present invention and incorporated herein by reference. An important feature is that both soft handoffs and softer handoffs make the new connection before breaking the existing one.

If a mobile station travels outside the boundary of the system with which it is currently communicating, it is desirable to maintain the communication link by transferring the call to a neighboring system, if one exists. The neighboring system may use any wireless technology, examples of which are CDMA, NAMPS, advanced mobile phone service (AMPS), time devision multiple access (TDMA), or global mobile systems (GSM). If the neighboring system uses CDMA on the same frequency band as the current system, an inter-system soft handoff can be performed. In situations where inter-system soft handoff is not available, the communication link is transferred through a hard handoff where the current connection is broken before a new one is made. Examples of typical hard handoff situations include: (1) the situation in which a mobile station is traveling from region serviced by a CDMA system to a region serviced by a system employing an alternate technology and (2) the situation in which a call is transferred between two CDMA systems which use different frequency bands (interfrequency hard handoff).

Inter-frequency hard handoffs can also occur between base stations of the same CDMA system. For example, a region of high demand such as a dense urban area may require a greater number of frequencies to service demand than the suburban region surrounding it. It may not be cost effective to deploy all available frequencies throughout the system. A call originating on a frequency deployed only in the high congestion area must be handed off as the user travels to a less congested area. Another example is system which encounters interference from another service operating on an interferring frequency within the system's boundaries. As users travel into an area suffering from interference from another service, their call may need to be handed off to a different frequency.

Handoffs can be initiated using a variety of techniques. Handoff techniques, including those using signal quality measurements to initiate a handoff, are found in copending U.S. Pat. No. 5,697,055 entitled "METHOD AND APPARATUS FOR HANDOFF BETWEEN COMMUNICATION SYSTEMS", U.S. Pat. No. 5,999,816, issued Dec. 9, 1997, assigned to the assignee of the present invention and incorporated herein by reference. Further disclosure of handoffs, including measurement of round-trip signal delay to initiate handoff, is disclosed in copending U.S. Pat. No. 5,848,063 entitled "METHOD AND APPARATUS FOR HARD HANDOFF IN A CDMA SYSTEM", issued Dec. 8, 1998, assigned to the assignee of the present invention and incorporated herein by reference. Handoffs from CDMA systems to alternate technology systems are disclosed in copending U.S. Pat. No. 5,594,718 entitled "METHOD AND APPARATUS FOR PROVIDING MOBILE UNIT ASSISTED HARD HANDOFF FROM A CDMA COMMUNICATION SYSTEM TO AN ALTERNATIVE ACCESS COMMUNICATION SYSTEM", issued Jan. 14, 1997, assigned to the assignee of the present invention and incorporated herein by reference. In the '718 patent, pilot beacons are placed at the boundaries of the system. When a mobile station reports these pilot beacons to the base station, the base station knows that the mobile station is approaching the boundary, and in response, prepares for the possibility of an intersystem hard handoff.

When a system has determined that a call should be transferred to another system via hard handoff, a message is

sent to the mobile station directing it to do so along with parameters that enable the mobile station to connect with the destination system. The system from which the mobile station is departing has only estimates of the mobile station's actual location and environment, so the parameters sent to the mobile station are not guaranteed to be accurate. For example, with beacon aided handoff, the measurement of the pilot beacon's signal strength can be a valid criteria for triggering the handoff. However, the appropriate base station or base stations in the destination system which can effectively communicate with the mobile station are not necessarily known. These base stations with which the mobile can effectively communicate and which are considered to be good candidates based upon additional criteria are maintained in a list or "set" within the mobile station and commonly referred to as the "Active Set". Inclusion in the active set implies allocation of foward link resources. Allocation of all possible candidates as opposed to the minimal sufficient set is wasteful of system resources, reducing available system capacity. Even if all of the base stations in the destination system which can effectively communicate with the mobile station are known, including all such base stations may exceed the maximum number allowable in the Active Set.

In order for the mobile station to communicate with the destination system, contact with the old system must cease. If the parameters given to the mobile station are not valid for any reason (i.e. changes in the mobile station's environment or lack of precise location information at the base station) the new communication link will not be formed, and the call may be dropped. After an unsuccessful handoff attempt, the mobile station can revert back to the previous system if it is still possible to do so. However, with no further information and no significant change in the mobile station's environment, repeated attempts to perform a handoff may also fail.

A method for performing additional hard handoff attempts with greater probability of success is disclosed in copending U.S. Patent entitled "METHOD AND APPARATUS FOR PERFORMING MOBILE ASSISTED HARD HANDOFF BETWEEN COMMUNICATION SYSTEMS", U.S. Pat. No. 5,999,816, issued Dec. 7, 1999 assigned to the assignee of the present invention and incorporated herein by reference. In the 5,999,816 patent, mobile stations tune temporarily to the frequency of the hard handoff destination system and search for available pilot signals (hereafter referred to simply as "pilots") on that frequency, for inclusion of the associated base stations in the active set. After the searching task is completed, the mobile station will retune to the original frequency to resume current communications. While tuned to an alternate frequency, any frames of data generated by the mobile station or transmitted by the base station will be corrupted. Typically, the base station will provide only a subset of the possible offsets (commonly referred to as an "enable list") for the mobile station to search. Even so, the duration of the searching can be so long as to potentially corrupt a number of frames of data. As such, there is a need for searching techniques which minimize the duration of time that a mobile station spends tuned to an alternate frequency so as to minimize corruption of the active communication link. Such searching techniques will clearly improve the quality of systems employing the hard handoff techniques described above.

SUMMARY OF THE INVENTION

The present invention is a method and apparatus for minimizing the amount of time that a mobile station is to be out of communication with an "origination" base station while searching for a suitable system to which to perform a mobile station assisted hard handoff.

In the present invention, after being directed to search for pilot signals in an alternate frequency band, the mobile station tunes to that alternate frequency and samples the incoming data, storing those samples in memory. During the time that the mobile station is tuned to the alternate frequency, all data being transmitted to the mobile station on the forward link is lost. Similarly, any reverse link data transmitted by the mobile station would be transmitted on the alternate frequency. Therefore, such reverse link data would not be received at the origination base station. When a sufficient number of samples have been stored, the mobile station retunes to the origination frequency. At this time, the forward link data is again received by the mobile station, and reverse link data can be successfully transmitted to the origination base station. After retuning to the origination frequency, a searcher in the mobile station will subsequently be employed to search for pilot signal offsets utilizing the stored data collected from the alternate frequency. In accordance with the present invention, due to the relatively short period of time required to sample and store information on the alternative frequency, the active communication link is not broken. Neither is the active communication link affected by the subsequent off-line search.

Because less time is required to sample the data on the alternate frequency than is required to actively search for pilot signals in real time, and because the communication link is corrupted by the hard handoff process only while the mobile station is tuned to the alternate frequency, the present invention minimizes the interruption of the forward and reverse links on the originating system. In fact, the error correction coding employed in modern communication systems can eliminate all errors introduced by sampling the alternate frequency, if the sampling time is small enough.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

FIG. 1 is a schematic overview of a spread spectrum CDMA communications system in accordance with the present invention;

FIGS. 2A–2B represent graphically the benefits of employing the present invention over the prior art;

FIG. 3 is an illustration of a mobile station in accordance with the present invention;

FIG. 4 is an illustration of one embodiment of a search engine used in the present;

FIG. 5 depicts the correlations necessary to search a window of offsets using sampled data in accordance with the present invention; and

FIG. 6 is an illustration of an alternate search engine configured for use in the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 depicts a communication system employing an embodiment of the present invention. Mobile station 5 is actively communicating with a 25 fixed communication system on a forward link 12 and reverse link 14 through an "origination" base station 10. Origination base station 10 is

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part of an "origination" system and transmits and receives information over forward link 12 and reverse link 14, respectively, on a first frequency, f1. Mobile station 5 is shown to be traveling from the origination system into a "destination" system which transmits and receives information on a second frequency, f2. The destination system includes "destination" base stations 20 and 22, which are not in active communication with mobile station 5. However, pilot signals (hereafter referred to simply as "pilots") from destination base stations 20 and 22 can be received by mobile station 5 if mobile station 5 is tuned to frequency f2. Both the origination and destination systems are part of the fixed communication system that allows the mobile station to communicate with other communication devices, such as conventional telephones wired to the public switch telephone network or other wireless communication devices. It should be understood that the fixed communication system can comprise any device or combination of devices that provides wireless communication between the mobile system and other communication devices.

In accordance with one embodiment of the present invention, origination base station 10 utilizes mobile station 5 in performing a mobile station assisted interfrequency hard handoff in accordance with the method and apparatus disclosed in copending U.S. Patent Application entitled "METHOD AND APPARATUS FOR PERFORMING MOBILE ASSISTED HARD HANDOFF BETWEEN COMMUNICATION SYSTEMS", Ser. No. 08/816,746, filed Feb. 18, 1997, assigned to the assignee of the present invention. Origination base station 10 transmits a "Tune_Message" to mobile station 5 directing it to tune to an alternate frequency, f2 in this case, and to search for a set of available pilots, the pilots of destination base stations 20 and 22, for example. It should be understood that in different systems, the particular criteria for which the mobile station searches will vary. Upon receipt of the Tune_Message, mobile station 5 tunes to frequency f2 and performs the search as directed. Once the search is completed, mobile station 5 retunes to frequency f1 and resumes communication with origination base station 10. Mobile station 5 transmits a message indicating the results from the search to origination base station 10 of the origination system. The origination system, in conjunction with the destination system, determines whether to perform a hard handoff and to which destination base station(s) in the destination system.

While mobile station 5 is tuned to frequency f2, all forward link traffic from origination base station 10 is lost and attempted transmission of reverse link data is futile, because such transmission would occur on frequency f2 and origination base station 10 does not monitor frequency f2. FIG. 2A plots the frequency used by a prior art mobile station 5 versus time. It is shown that while the mobile station is tuning to f2, performing the search, and retuning to f1 that erasures of traffic data are occurring. In one IS-95 system, depending on the number of offsets prescribed to search, several 20 ms frames of data could be lost during the erasure period.

In accordance with the present invention, when mobile station 5 is directed to tune to frequency f2 by origination base station 10, instead of searching for prescribed offsets, as was done in the prior art, mobile station 5 records samples of the signal on frequency f2 and stores those samples in memory. It will be understood that any memory device that is capable of saving the information for processing at a later time can be used, such as a random access memory (RAM). As soon as a sufficient number of samples have been taken,

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mobile station 5 retunes to frequency f1 and resumes communication with origination base station 10 over the forward and reverse links 12, 14.

FIG. 2B illustrates the amount of time during which the mobile station 5 is tuned to frequency f2 in accordance with the present invention with respect to the amount of time required in the prior art as shown in FIG. 2A. Once data is captured, the search is performed off-line (i.e., while the mobile station 5 is tuned to frequency f1). Accordingly, communications resume between mobile station 5 and origination base station 10 more quickly than is possible if the information that is received is processed while the receiver remains tuned to frequency f2. The duration of time that erasures are introduced by being tuned to frequency f2 is significantly less with the present invention than with the methods of the prior art. In an IS-95 system, the tuning and retuning can be performed in approximately 4 ms. The memory size requirements in such a system allows for 512 chips of data sampled at twice the chip rate, with 4 bits/sample for both the I and Q channels. This results in a storage requirement of 1024 bytes. It will be obvious to one skilled in the art that alternate values can be substituted for those above, each with known tradeoffs in complexity and performance. The capture time in such an embodiment of the present invention is approximately 0.5 ms. An IS-95 data frame is 20 ms in duration. Therefore, for this example the total erasure time of approximately 5 ms does not even corrupt an entire frame.

In accordance with one embodiment, the search for an alternate frequency f2 is aligned with lower rate frames, such as ⅛ rate frames. In this case, the amount of data erased will often be so insignificant as to be correctable by coding and interleaving, such that no errors result.

In an alternative embodiment, to reduce memory requirements, a smaller sample size can be recorded from frequency f2. Those results can be used to compute partial results in an off-line search. Return trips to frequency f2 by mobile station 5 can be performed until the search results are complete. Examples of search implementations are described below.

FIG. 2B shows that the time required for searching is the same as in FIG. 2A, even though the search is performed while receiving and transmitting on f1. However, as can be seen from FIG. 2B, determining the final search result requires more time due to the fact that the search and the capture are not done concurrently, as shown in FIG. 2B. Nonetheless, intermediate search results can be transmitted to origination base station 10 as they become available, since mobile station 5 is in communication with origination base station 10 during the search.

The present invention results in a further improvement, because the off-line search need not be performed in "real time". The search can be performed as fast as current technology allows the circuits to run, or within power budgets, a tradeoff common in the art. As such, the system can be designed so that both the erasure rate and search time are greatly reduced in comparison with the methods of the prior art.

Because of the possibility of rapid variations in the received signal due to the changing environment in which mobile station 5 operates, it may be desirable to repeat the process of sampling the alternate frequency f2 a number of times if a large number of offsets are to be searched. Repeating the process allows for use of fresh data, while the improvements provided by the present invention reduce the frame error cost associated with repeat ventures to the alternate frequency.

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FIG. 3 depicts a block diagram of one embodiment of a mobile station 5 in accordance with the present invention. Forward link signals are received at antenna 50 and passed through duplexer 60 to receiver 70. Initially, receiver 70 is directed to receive on frequency $f1$. After downconversion and amplification in receiver 70, the forward link signals are demodulated according to the IS-95 standard in a demodulator (not shown). In normal operation, the received signal is simultaneously sent to searcher 100 through multiplexer ("mux") 90 for non-handoff search processing.

When a Tune_Message is received from the base station directing the mobile station to tune to frequency $f2$, control processor 110 directs receiver 70 to tune to frequency $f2$. Communications with origination base station 10 will be interrupted while mobile station 5 is tuned to frequency $f2$. Control processor 110 further directs memory 80 to begin storing samples of the incoming signal at the prescribed sampling rate. After the predetermined number of samples have been collected in memory 80, control processor 110 directs receiver 70 to retune to frequency $f1$. Subsequently, normal communication with origination base station 10 resumes.

Meanwhile, control processor 110 initiates the off-line search. This is accomplished by directing mux 90 to cease directing samples from receiver 70 to searcher 100, and to instead direct samples from memory 80 to searcher 100. Searcher 100 can be any searcher type, some of which are described below as examples. Control processor 110 directs searcher 100 to complete the search of each offset given in the prescribed set of offsets received from origination base station 10. When results become available from searcher 100, control processor 110 delivers those results to message generator 120. In one instance, the results are based upon hypotheses, as is known in the art. Control processor 110 can transfer each result as it becomes available for transmission, or it can wait until all hypotheses to have been searched. Control processor 110 can select a subset of pilots detected based on signal strength, for example, for delivery to origination base station 10, or all pilot data can be transmitted for further processing in the base station.

Message generator 120 formats the results into messages suitable for transmission by transmitter 130. Implicit in transmitter 130 is a modulator, which modulates according to the IS-95 standard in the preferred embodiment. The reverse link signal generated in transmitter 130 is provided for transmission on antenna 50 through duplexer 60.

In one embodiment of the present invention, searcher 100 comprises a search engine, such as is disclosed in copending U.S. Pat. No. 5,805,648 entitled "METHOD AND APPARATUS FOR PERFORMING SEARCH ACQUISITION IN A CDMA COMMUNICATION SYSTEM", issued Sep. 8, 1998, assigned to the assignee of the present invention and incorporated herein by reference. The searcher described in the '648 patent employs a multiple dwell serial acquisition technique. As mentioned above, any search technique can be used in the present invention, and many such techniques are well known in the art.

FIG. 4 is a block diagram of the search engine as disclosed in the '648 patent. As described above, I and Q samples come from those stored in memory while mobile station 5 was tuned to alternate frequency $f2$, or the samples come from those currently generated in receiver 70 for use in real time searching. Techniques for real time searching, such as disclosed in the '721 application, are well known in the art. The technique for searching the stored samples from alternate frequency $f2$ will be described in detail below.

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I and Q samples enter despreader 206 and are despread using PNI and PNQ sequences as generated by PN sequence generator 200. In one embodiment of the present invention, the PN sequences generated in PN sequence generator 200 are generated using maximal length shift registers (not shown). Despreader 206 multiplies each I and Q sample by the corresponding PNI and PNQ value and provides those two output products to coherent accumulators 208 and 210.

When performing off line searching, it is important to "rewind" the maximal length shift registers inside of PN sequence generator 200 to align the PNI and PNQ sequences with the sequences that were used to generate the signals from which the I and Q samples were recorded. A hypothetical phase offset to search is given to PN sequence generator 200 by searcher controller 218, and that hypothesis is tested as described below.

The despread I and Q values are accumulated in coherent accumulators 208 and 210, respectively. The duration of the accumulation in accumulators 208 and 210 is determined by searcher controller 218. Each accumulation from accumulators 208 and 210 is squared and those results are summed in squaring means 212. The sum of the squares is provided by squaring means 212 to noncoherent accumulator 214. Noncoherent accumulator 214 determines an energy value from the output of squaring means 212 by accumulating for a duration, M, given by searcher controller 218. Noncoherent accumulator 214 serves to counteract the effects of a frequency discrepancy between the base station transmit clock and the mobile station receive clock and aids in the detection statistic in a fading environment. Noncoherent accumulator 214 provides the energy signal to threshold comparer 216. Threshold comparer 216 compares the energy value to a threshold provided by searcher controller 218. Searcher controller 218 can examine the results of the comparisons and determine whether the current offset hypothesis being searched is likely to contain a valid pilot signal and thus be usable for demodulation.

FIG. 5 depicts the correlations required to search a window of hypotheses from offset 0 to offset M. First, an offset of 0 is searched. PN sequence generator 200 is "rewound" to the state that was current when the I and Q samples were recorded. Then the 0th PNI and PNQ value are used to despread the 0th I and Q data values, respectively, as depicted by the alignment of PN sequence 510 with data sequence 500. Each subsequent value of PNI and PNQ is used to despread the corresponding data values until the Nth values have been despread. These despread values are processed as described above.

Following the conclusion of the search of offset 0, an offset of 1 is to be searched. PN sequence generator 200 is "rewound" to offset 1, and despreading occurs as described for offset 0 above, except the despreading is done as shown by the alignment of PN sequence 520 with data sequence 500. In this case, PN sequence 1 is used to despread data sequence 0, and so on until PN sequence N+1 is used to despread data sequence N. Again the despread values are processed as described above until the offset 1 search is complete. Offset 2 is searched as shown by the alignment of PN sequence 530 with data sequence 500. The foregoing process is repeated as necessary until M+1 offsets have been searched, as depicted by the alignment of PN sequence 540 with data sequence 500. Although the foregoing example of a linear sweep of M+1 offsets was used to describe the present invention, it is clear that in practice any set of offsets could be searched in any order deemed appropriate.

An alternate embodiment of the search engine of searcher 100 is a modification to the well-known technique of

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employing a matched filter for acquisition of a spread spectrum signal. This matched filter technique is described in "Spread Spectrum Communications Handbook", by Simon, et. al., published by McGraw-Hill, Inc., in part 4, chapter 1, section 1.5.

FIG. 6 shows the embodiment of a modified matched filter search engine which affords benefits particular to the present invention. Data is input to the serial chain of delay elements 600A–600N. During each cycle, the data stored in delay elements 600A–600N are multiplied in multipliers 620A–620N with tap values 610A–610N. The tap values are determined by a section of the PN sequence with which the data is to be correlated. Tap values 610A–610N remain constant for the duration of the hypothesis test. Tap values 610A–610N can be parallel loaded or serially shifted in, as shown, when a different section of the PN sequence is to be correlated. The results of multipliers 620A–620N are summed in summer 630 and provided to threshold compare block 640. Threshold compare block 640 compares the output of summer 630 with a threshold provided by search controller 650. When a threshold has been exceeded, it is likely that a valid pilot signal is present at the offset given by the segment of the PN sequence currently stored in tap values 610A–610N. Search controller 650 also controls the shifting of data into delay elements 600A–600N as well as the updating of tap values 610A–610N.

When this search engine is used in real time search mode, data can be shifted in to delay elements 600A–600N and correlated with a predetermined segment of the PN sequence stored in tap elements 610A–610N, just as is done in the prior art. However, when the searcher is to be used in off-line searching to facilitate the mobile station assisted hard handoff, under control of search controller 650 the sampled alternate frequency f2 data can be shifted into delay elements 600A–600N. Once loaded, no further shifting of data will occur in delay elements 600A–600N. Then tap elements 610A–610N can be used to continuously shift in PN sequence data to correlate with the fixed length of stored data in delay elements 600A–600N. In this manner, the data in delay elements 600A–600N have effectively become the tap values of the matched filter, and the tap values 610A–610N serve as data delay elements. The rest of the circuitry is used in exactly the same manner as described above. Hence, under simple control by search controller 650 this modified matched filter search engine can easily be switched between standard on-line searching of real time data and off-line searching of stored data in accordance with the present invention.

The previous description of the preferred embodiments is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

What is claimed is:

1. A method for minimizing the amount of time during which communication between a mobile station and a fixed communication system is lost during hard handoff, the method comprising the steps of:

(a) tuning a receiver from an origination frequency to an alternative frequency;

(b) receiving signals at the alternative frequency from destination base stations;

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(c) storing the signals received at the alternative frequency;

(d) retuning the receiver to the origination frequency;

(e) at the mobile station concurrently both:

(e1) receiving signals at the origination frequency from an origination base station; and

(e2) analyzing the stored signals to determine whether the alternative frequency can support communications between the mobile station and the destination base stations; and

(f) enabling hard handoff of the mobile station from the origination base station to the destination base station if the analysis of the stored signals determines that the alternative frequency can support communications between the mobile station and the destination base station.

2. The method of claim 1, further comprising the step of the origination base station transmitting a tune message to the mobile station, said tune message directing the mobile station to tune to the alternative frequency.

3. A method for use in a communications system which includes:

(a) an origination base station operating at an origination frequency;

(b) destination base stations operating at an alternative frequency; and

(c) a mobile station tunable to operate at either the origination frequency or the alternative frequency;

the method being characterized by the steps of:

(d) the mobile station tuning from the origination frequency to the alternative frequency;

(e) the mobile station receiving signals at the alternative frequency from the destination base stations;

(f) storing the signals received at the alternative frequency;

(g) the mobile station retuning to the origination frequency;

(h) at the mobile station concurrently both:

(h1A) transmitting signals to the origination base station;

(h1B) receiving signals from the origination base station; or

(h1C) both transmitting signals to and receiving signals from the origination base station; at the origination frequency; and

(h2) analyzing the stored signals to determine whether the alternative frequency can support communications between the mobile station and the destination base stations; and

(i) enabling hard handoff of the mobile station from the origination base station to the destination base station if the analysis of the stored signals determines that the alternative frequency can support communications between the mobile station and the destination base station.

4. The method of claim 3, further characterized by including the step of the origination base station transmitting a tune message to the mobile station, said tune message directing the mobile station to tune to the alternative frequency.

5. Apparatus for minimizing the amount of time during which communication between a mobile station and a fixed communication system is lost during hard handoff, the apparatus comprising:

(a) means for tuning a receiver from an origination frequency to an alternative frequency;

(b) means for receiving signals at the alternative frequency from destination base stations;

(c) means for storing the signals received at the alternative frequency;

(d) means for retuning the receiver to the origination frequency;

(e) means, at the mobile station, for concurrently both:
  (e1) receiving signals at the origination frequency from an origination base station; and
  (e2) analyzing the stored signals to determine whether the alternative frequency can support communications between the mobile station and the destination base stations; and

(f) means for enabling hard handoff of the mobile station from the origination base station to the destination base station if the analysis of the stored signals determines that the alternative frequency can support communications between the mobile station and the destination base station.

6. The apparatus of claim 5, further comprising means for the origination base station transmitting a tune message to the mobile station, said tune message directing the mobile station to tune to the alternative frequency.

7. Apparatus for use in a communications system which includes:

(a) an origination base station operating at an origination frequency;

(b) destination base stations operating at an alternative frequency; and

(c) a mobile station tunable to operate at either the origination frequency or the alternative frequency;

the apparatus being characterized by:

(d) means for the mobile station tuning from the origination frequency to the alternative frequency;

(e) means for the mobile station receiving signals at the alternative frequency from the destination base station;

(f) means for storing the signals received at the alternative frequency;

(g) means for the mobile station retuning to the origination frequency;

(h) means, at the mobile station, for concurrently both:
  (h1A) transmitting signals to the origination base station;
  (h1B) receiving signals from the origination base station; or
  (h1C) both transmitting signals to and receiving signals from the origination base station; at the origination frequency; and
  (h2) analyzing the stored signals to determine whether the alternative frequency can support communications between the mobile station and the destination base stations; and

(i) means for enabling hard handoff of the mobile station from the origination base station to the destination base station if the analysis of the stored signals determines that the alternative frequency can support communications between the mobile station and the destination base station.

8. The apparatus of claim 7, further characterized by including means for the origination base station transmitting a tune message to the mobile station, said tune message directing the mobile station to tune to the alternative frequency.

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